TESTIMONY BY MR. K.G.DULEEP AT THE HEARING ON IMPROVING THE NATION'S ENERGY SECURITY: CAN CARS AND TRUCKS BE MADE MORE FUEL-EFFICIENT?

Mr. Chairman and Members of the House Science Committee,

Thank you for inviting me to participate in this hearing on the topic of vehicle fuel efficiency. I am the Managing Director at Energy & Environmental Analysis (EEA), a consulting firm. EEA has been involved in analyzing this topic for the last 25 years and has provided the Department of Energy with many analyses of technologies over this period. EEA has also worked for a number of foreign governments, notably Canada and Australia, on this issue. The views expressed by me at this hearing, however, are my own and do not reflect the views of the DOE or any of my other clients. I was instructed by the committee's staff to respond to four questions, and I will focus on these questions in my testimony. I have highlighted the key points in my written testimony

CONVENTIONAL TECHNOLOGY IMPROVEMENTS

The first question posed was on the identification of technologies available to improve light-duty vehicle fuel economy and their potential benefit. This is a question that has received much attention and most analyses separate "conventional" technologies that are evolutionary improvements to existing technology from "revolutionary" technologies that involve new types of engines and/or fuels. In this context, hybrid and diesel vehicles could be described as revolutionary and their benefits are described in the response to the second question. All of the fuel economy benefits cited are on the EPA combined city-highway test unless an alternative is specifically mentioned.

The available conventional technologies have been extensively researched and I can state that there is a consensus among engineers regarding these technologies and their costs and benefits. Table 1 (attached) provides such a listing and is restricted to conventional technologies that are sold in at least one mass-market model in the US as of 2005, to avoid any controversy about technology readiness for the market place. In addition, I have ignored the potential for weight reduction through the use of alternative materials because of the unfortunate controversy over the link between weight and safety. The data in the table suggests that a total fuel economy improvement of about 26 percent in small cars to 28 percent in larger cars and light trucks is possible for much of the new car fleet with no weight reduction whatsoever. At the same time it should be noted that all of the technologies are (by definition) in some vehicles, so that the fleetwide benefit available relative to 2004 model year vehicles is about 2 percent lower than the estimate in the table. If one were to choose only those technologies that pay for themselves in terms of fuel savings over 50,000 miles (a measure used by manufacturers to gauge consumer acceptance), then the gasoline direct injection system would not be included in the list. However, direct injection with lean combustion could be cost effective as it could double the fuel economy benefit from this technology alone and eliminate the need to employ cylinder de-activation or variable valve lift. Hence, **the available improvement from cost effective conventional technology would be about 24 to 26 percent.** Half of the improvement is associated with engine technology. The technologies would add about

$800 to $1000 to the retail price of a vehicle while the value of fuel saved over 50,000 miles at $2/gallon would be in the same range.

These estimates are a little lower than the ones derived by the National Academy of Sciences for two reasons. First, the choice of only those technologies already in the market as of 2005 is more restrictive than the definition used by the NAS. Adding most of the excluded technologies like "camless valve actuation" or " variable compression ratio" will increase the total available benefit but will not change the listing of cost-effective technology as these excluded technologies are typically quite expensive for the benefit delivered. Second, the NAS study was completed four years ago and some of the technologies on their list have already been widely adopted in the interim period. However, it can be argued that the costs of these excluded technology improvements could come down in the future. A comparison of studies on fuel economy completed since 1985 suggests that **at any given point in time, there always appears to be the potential to increase fuel economy by 25 to 30 percent in a cost-effective way.** As available technologies are adopted into most new cars, new technologies are developed to lead to this conclusion.

More importantly, I also believe that **all of the cost-effective technology in the table could be adopted under free market conditions in most vehicles** by 2015 if gasoline prices do not decline significantly, simply due to the fact these technologies pay for themselves. As examples, GM has publicly announced that most of the V-8 and V-6 engines will have cylinder cutout in the future. GM and Ford are collaborating on a six speed automatic transmission that will be used on most of their front wheel drive cars by 2012. Daimler-Chrysler's new four-cylinder engine will be equipped with variable valve timing. Most current Honda models offer variable valve lift systems. These examples confirm our computations of cost-effectiveness. At the same time, this does not imply that 2015 fuel economy under free market conditions will be 25 percent higher than it is today. **We estimate that about half of the improvement will counterbalanced by consumers buying more luxurious and larger vehicles, SUV models and four-wheel drive** even if fuel prices remain at around $2 per gallon. If gasoline prices decline in the future to $1.25 per gallon, there may be no improvement in fleet fuel economy at all as some technologies become cost ineffective.

HYBRID AND DIESEL TECHNOLOGY

The second question asks about the prospects for diesel and hybrid technology, and their expected contribution to fuel economy. Dr. Greene of Oak Ridge National Laboratory and I completed a study of these technologies last year on this very question, but because technological changes are happening quickly, I have modified my answers to reflect new data. I will focus on technology issues and let Dr. Greene respond to market penetration issues. Both technologies offer the prospect for fuel economy improvements of 40 to 50

TABLE 1: CONVENTIONAL TECHNOLOGIES TO IMPROVE FUEL ECONOMY FOR THE 2005 TO 2015 TIME FRAME

(technologies introduced in at least one model in the US market)

		TECHNOLOGY	**F/E(%) BENEFIT***		**COMMENT**
ENGINE		VARIABLE VALVE TIMING	2 ± 0.5		ALLREADY USED ON MANY CARS
		VARIABLE VALVE LIFT or	5 ± 1.0		USED PRIMARILY BY HONDA AND BMW
		CYLINDER CUTOUT (V-6 & V-8 ONLY)	8 ± 1.0		INTRO. ON V-8 BY GM & CHRYSLER IN ‘05
		ENGINE FRICTION REDUCTION	2 ± 1.0		ADOPTED IN VARYING DEGREES
		DIRECT INJECTION (stoichiometric)	5.5 ± 1.0		INTRO. BY AUDI IN 2005 A6
TRANS-MISSION		6 SPEED AUTOMATIC (V-6 & V-8) or	4 ± 1.0		INTRODUCED IN SOME LUXURY CARS
		CVT (4 CYLINDER) relative to 4-speed unit	5 ± 1.0		INTRODUCED BY HONDA AND GM
		LOW LOSS TORQUE CONVERTER	1.5 ± 0.5		INTRODUCED IN SOME LUXURY CARS
OTHER		IMPROVED WATER, OIL PUMP	1 ± 0.3		ELECTRIC DRIVE MAY SAVE MORE
		IMPROVED ALTERNATOR	0.5 ± 0.2		APPEARING IN SOME HIGH FE MODELS
		ELECTRIC POWER STEERING	2 ± 0.5		INTRODUCED BY GM IN 2005 MALIBU
		REDUCED TIRE ROLLING FRICTION	2 ± 1.0		INTRODUCED IN HYBRID MODELS
		REDUCED AERO. DRAG	2 ± 0.5		ADOPTED IN VARYING DEGREES
TOTAL		ALL IMPROVEMENTS IN ONE VEHICLE	26 ± 2.5		4 CYLINDER
			28 ± 2.5		V-6 AND V-8

*FE benefits are measured at constant performance, defined as constant torque/weight over typical driving conditions. Individual benefits of technologies shown above are not necessarily additive for groups of technologies in the same vehicle.

** All technologies except direct injection are cost effective at $2 per gallon in terms of fuel savings exceeding technology price over 50,000 miles of driving on midsize car. Technologies in “other” category are marginal and may not be cost effective at lower gasoline prices.

percent, more than double the total available from all cost effective conventional technology.

Diesel engines are not a new technology and half of all new cars sold in Europe are diesel powered. They are revolutionary only in the US context due to the difficulty in meeting emissions standards in force here. Although much has been made of the diesel's emissions, I am now reasonably confident that **the diesel engine will be able to meet the stringent new Tier 2 emission standards in most vehicles in the near future**. Existing diesel engines can definitely meet this standard with an urea-SCR system and particulate trap, but vehicles need periodic refueling with urea. Distributing urea to refueling stations is not an insurmountable problem, but is of some concern to the EPA. Other solutions that do not require urea like the NOx adsorber are also close to meeting emission standards but extract a fuel economy penalty of 3 to 5 percent. More exciting developments are in emission control by modifying the combustion process itself. There are three approaches being pursued, and the US EPA has developed one. Last week, Ford and EPA announced an agreement to develop this technology for production, demonstrating its potential.

Modern diesel engines with direct injection and turbocharging can improve fuel economy by 38 ± 5 percent relative to a gasoline engine of equal size [1]. These engines can provide 40 to 50 percent more mid-range torque than the gasoline engine and near equal horsepower. In addition, there is evidence from Europe that diesel vehicles perform better on the road than gasoline vehicles and real-world (as opposed to EPA test) fuel economy may be about 50 percent better than a gasoline vehicle. However, the diesel engine (with advanced emission control) will have a **price premium of about $2200 for a four cylinder engine used in a compact car to about $3400 for a large V6 used in a pickup truck.** At these prices, the fuel savings over 50,000 miles will not pay for the full cost, but consumers value the torque and durability of the engine. I should also note that the "conventional" technologies not related to the gasoline engine in Table 1 are also applicable to diesel powered vehicles, so that **the vehicle fuel economy potential is about 50 ± 6 percent.** Our study estimated the ultimate market potential of the diesel in the 2015 time frame at about 30 percent of the market if there is no hybrid competition.

The hybrid gasoline –electric vehicle has received much attention, but there are many kinds of hybrids and the terminology to describe them is both confusing and biased. The Toyota Prius is one reference sometimes referred to as a "full" hybrid, and it uses two high powered electric motors, a gasoline engine and a high power battery. (Ford's Escape hybrid uses a similar system). The Honda Civic and Accord hybrids use a different and simpler system with one motor of relatively low power and a smaller battery than the one used in the Toyota Prius. GM and Daimler Chrysler currently offer a system in a hybrid pickup truck conceptually similar to the Honda system but with a much lower energy battery. GM also plans to introduce a fourth type of system, called a Belt drive Alternator Starter (BAS) system that is significantly cheaper than any of the other systems. All of these types are hybrids but have quite different price and performance implications.

[1] Europeans often quote a diesel fuel consumption (the inverse of fuel economy) benefit of 25 to 30 percent, and this is equal to a fuel economy benefit of 33.3 to 42.85 percent.

In general, **all hybrids improve fuel economy in city (or stop-and-go) driving by significant amounts, but offer little or no improvement in fuel economy under highway (steady high speed) conditions.** In addition, the hybrid vehicle's fuel economy benefits, even under city driving conditions, are a function of trip length and ambient conditions. In contrast, the fuel economy benefit of the diesel is more robust across all driving conditions.

It is difficult to provide a single fuel economy benefit number to hybrids even of a particular type since it is a function of the performance trade-offs chosen by the manufacturer. **"Full" Hybrids using a two electric motor design similar to that used by Toyota and Ford can provide a 50 to 55 percent improvement in composite fuel economy if optimized for maximum fuel efficiency**. This improvement includes the effect of the conventional technologies listed in Table 1 and the benefit of hybridization alone is about 25 to 30 percent. Such hybrids provide comparable low speed acceleration but reduced continuous power for hill climb or trailer towing. Vehicles that offer no compromise in continuous power and significantly better low speed acceleration will offer a benefit of 30 to 35 percent (again including most conventional technologies). In a midsize car for example, we estimate that the additional hybrid related components will add $5600 to retail price currently if manufacturers utilize standard retail markup and expect to earn an average profit margin on these vehicles. There are significant cost reductions likely to be realized over the next 5 years and we estimate that by 2010 prices can be below $3900. Since the fuel savings over 50,000 miles are only on the order of $1300 to $1500, many believe that this technology will never succeed in the market even after cost reductions are realized.

These issues regarding the "full" hybrid have been debated publicly, but the potential of other hybrid designs has received much less attention in the press. Honda has introduced three hybrid vehicles in the US that have a single electric motor of less than half the power of the motors in the Toyota Prius, and an advanced battery that is half the size of the one in the Prius. Yet, the fuel economy gains in the Honda hybrid vehicles are almost as good as the ones from the Toyota hybrids. Honda has cleverly managed to exploit synergies between engine, transmission and electric motor technology to maximize fuel economy. We estimate the cost of these hybrids to be less than half the cost the "full" hybrid designs, so that future prices will be relatively close to the value of fuel saved. Other innovative designs using ultra-capacitors have been shown by Continental of Germany that could be a low cost solution for some types of vehicles. **These alternative types of hybrid designs in synergy with engine technologies could provide fuel economy gains of 30 to 35 percent with no loss in performance, and will be cost effective in terms of fuel savings over the life of the vehicle.** Dr. Greene's analysis suggests that hybrids of different types can capture 25 percent of the market by 2015, and this figure could be higher with some of the more innovative designs under study now.

Some analysts have discounted the diesel engine and hybrid powertrain combination as too expensive, but I do not agree. Some alternative cheaper hybrid designs could make sense with advanced diesel engines by eliminating the need for costly emission control equipment like NOx adsorbers, partially offsetting hybrid costs. I have heard that several European manufacturers are developing hybrid- diesel combinations and I anticipate that the first models will be available in the US by 2008.

SAFETY RELATED EFFECTS

The **data presented above for conventional and revolutionary technology do not include any weight or size reduction, so there are no reasons to be concerned for safety**. In addition, both the diesel and hybrid vehicle weigh 3 to 5 percent more than conventional vehicles, so that there could be positive benefits if weight is indeed a factor. I am not a safety expert, but recent analyses sponsored by Honda suggest that size rather than weight is more important for safety.

In addition, the safety relationship to weight and size is debated in the context of injury after a crash has occurred. This committee should be made aware of amazing new advances in active crash prevention technologies. Technologies being introduced into the marketplace in the near term include

- Blind Spot Warning through radar or infra-red detection
- Pre-Crash sensing using radar or vision based technology
- Lane Departure Warning using camera based technology
- Active Lane Keeping systems
- Stability control, soon to be standard on most vehicles
- Rollover prevention on trucks and SUV models
- Rear Vision and Night Vision systems
- Drowsy Driver Detection systems

Indeed, there are plans to incorporate systems to completely sense the vehicle driving environment and warn the driver or prevent a crash. **I believe that active safety technology has the potential to completely change the safety debate and remove any link between fuel economy and safety,** and hope that this committee will examine these technologies more closely.

GOVERNMENT POLICIES

I was also asked to comment on government policies to accelerate technology introduction. I am aware of public initiatives to raise CAFÉ standards with the premise that this policy has worked in the past. While the CAFÉ standards did achieve the goals, there is no question that the current form of the standard requiring all manufacturers to meet the same MPG target disadvantaged domestic manufacturers. Dr Greene and I have investigated **other forms of the standard such as size or weight based standards and these seem to be more equitable in treatment of different manufacturers. However, no form of standard is without some drawbacks, and all are susceptible to "gaming".** I am also hesitant to suggest the European method that set a "voluntary" fuel consumption improvement target for all manufacturers and let the manufacturers negotiate individual targets between themselves. I understand some strains are being caused between European manufacturers by this agreement, and intra-industry agreements could be construed as anti-competitive behavior under US laws. I will let others on the panel comment on standards and focus my attention on promoting technology for fuel economy.

The consumer side of the equation should also not be neglected. Consumers appear to value other attributes, notably size, luxury features and performance over fuel economy, and the appeal for SUV models has not diminished much even at the current gasoline price of $2 per gallon. The market share for light trucks continues to increase and reached a record of almost 55 percent of the total light vehicle market in 2004. Cars and light trucks with astounding horsepower ratings of 400, 500 and 600 HP are in demand in a country where the national speed limit rarely exceeds 70 mph. These trends will serve to eventually erase the benefits of any amount of technology introduction. Hence, future fuel economy related efforts should include efforts directed at consumer motivation to purchase more efficient rather than more powerful or larger vehicles. This has always been a difficult area for Congress, as any restriction on consumer choice appears politically unacceptable.

Just a few years ago, many economists believed that raising fuel prices alone would solve this problem of consumer motivation. Some computations purported to show that gasoline savings equivalent to a 25 percent increase in CAFÉ standards could be obtained by raising the fuel price to $1.75 (or by about 50 cents) at that time. It can now be demonstrated from US data from 2003-2004 that the assumed elasticities of consumer response to gasoline prices for vehicle choice and vehicle use were in error, by almost an order of magnitude. The Canadian experience with high fuel prices for the last 20 years also proves the same point. Hence, **increasing taxes on gasoline as the primary conservation measure is not a particularly powerful strategy unless very large price increases ($2 to $3) are contemplated.** At the same time, higher gasoline prices do make some modest contribution to saving fuel and can set the stage for making higher priced fuel efficient technology more palatable to the consumer, i.e. it may be a necessary but not a sufficient condition.

Subsidies and fees for fuel efficiency or fuel-efficient technology to motivate consumer purchase are a common suggestion, and there are some subsidies now available for hybrid vehicles. I believe that the experience has shown technology specific credit or subsidy programs to be quite unpredictable in supporting the best outcome. For example, California’s current ZEV mandate provides credits to hybrid vehicles as a function of electric motor power and battery voltage, independent of the actual fuel economy or emissions results attained by a specific design. In future, this could have the effect of promoting more expensive designs and disfavoring less expensive but more innovative designs that provides a similar outcome. I also believe that **diesel and hybrid technologies are not in direct competition**, as the primary benefits of hybrids accrue to passenger vehicles which operate mostly under city driving conditions. Diesel technology is most useful for vehicles that carry loads, tow trailers occasionally, and/or operate primarily on the highway. Hence, the availability of both diesel and hybrid technologies in the marketplace would extend benefits to different groups of consumers with different needs.

I would suggest tax rebates or subsidies for fuel efficient vehicles that are independent of technology, be it advanced diesel, gasoline direct injection, hybrid or

some combination. These subsidies could be phased out over a 10 year period, and the main purpose would be to reduce manufacturer's risk of investing in the production of a high fuel economy technology that is rejected by the consumer.

Thank you for your attention. I will be pleased to answer any questions the committee may have for me.

Biography for Mr. K.G. Duleep

As Managing Director at EEA, Mr. K.G. Duleep has been involved with automotive technology, fuel economy, and emissions issues for nearly 25 years. He has directed a number of studies evaluating new technologies for vehicular engine and fuel combinations (including methanol, natural gas, and other alternative fueled vehicles). These studies have compared the technical feasibility, economics, performance, maintenance, and air emissions impacts of alternative vehicle technologies. Mr. Duleep has completed projects for the U.S. Federal and State governments, and for several other countries (notably Canada and Australia) where his technology evaluations and forecasts have formed the basis for fuel economy related initiatives and regulations. Mr. Duleep has testified on transportation technology issues for the U.S. Congress during debates on the Clean Air Act and CAFE (fuel economy) standards during the 1990s.

In 2000, Mr. Duleep supported the National Academy of Sciences' Committee on the Effectiveness and Impact of CAFE Standards by providing information to the committee on the availability, cost and benefit of several automotive technologies. Much of the data on the cost of fuel economy and alternative fuel technology available in the public domain can be traced to his work for the Department of Energy. He also provides technology analysis support to auto-manufacturers and Tier 1 suppliers.

Mr. Duleep has a Masters' degree in Engineering from the University of Michigan and an MBA from Wharton.